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PATENT APPLICATION

Docket No.: D375

Inventor(s): Michael A. Rolenz

Title: Laser Communications Crosslink System

SPECIFICATION

Statement of Government Interest

The invention was made with Government support under contract No. F04701-93-C-0094 by the Department of the Air Force. The Government has certain rights in the invention.

Field of the Invention

The invention relates to the field of communications. More particularly, the present invention relates to laser satellite crosslink or fiber optics communication channels.

Background of the Invention

4 Transmitters and receivers have long been used to communicate
5 communication signals over a communication channel such as a
6 unidirectional crosslink. The transmitter receives an analog input
7 signal that is converted into digital form using a digital to
8 analog converter providing a parallel output that is then converted
9 into a serial data stream using a parallel to serial converter.
10 The serial data bits stream is expanded to include frame
11 synchronization words and forward error correction bits prior to
12 transmission over the communications crosslink. The communicated
13 signal is received by a receiver that performs forward error
14 correction. The synchronization is achieved during removal of the
15 frame synchronization words. The serial data stream is then
16 converted into a parallel data stream using a serial to parallel
17 converter. The parallel data stream can then be input into a
18 digital to analog converter for providing the original analog input
19 signal.

21 On the transmitter side of the communication channel, the
22 analog signal has a baseband bandwidth of $+/-f$ and is converted to
23 n bit data words by the analog to digital converter at a sampling
24 rate exceeding the Nyquist rate of $2f$ samples per second. These n
25 bit data words are parallel data bit signals that are converted
26 into a serial bit stream at a rate of $2fn$ bps. To determine the
27 ordering of the least to most significance bits of the data words
28 in the serial bit stream, unique and easily identifiable

1 synchronization frame words are periodically inserted into the
2 serial data stream. These synchronization frames words are
3 overhead data and are typically one to ten percent of the
4 informational data words. This overhead data increases the
5 required rate of bits transmitted per second to $(2fn(1+s/100))$ bps
6 where s is the percentage of the serial bit stream associated with
7 synchronization frame words. To accomplish the communications at
8 the original data bit, the serial stream including the frame words
9 and redundant error correction bits must be reclocked to a higher
10 data rate having a shorter bit duration time. In order to maintain
11 data rate of the data words when the serial bit stream has
12 additional synchronization frame words, the serial bit stream will
13 be clocked at a higher rate. The received data stream must also
14 therefore be reclocked to recover the original data. Non integer
15 multiples of the transmitted data require frequency synthesizers
16 and other digital word buffers.

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18 Frame synchronization words are added to separate the groups
19 of data words into frames of data words. Redundant error
20 correction bits are also added at a particular code rate that
21 relates the number of information data bits to the total number of
22 communicated bits. Forward error correction redundant bits are
23 added at a predetermined code rate to the data stream to correct
24 for transmission errors. The forward error correction increases
25 the actual data rate to $2fn(1+s/100)/r$ where r is the code rate.
26 The data stream is then transmitted over the communication channel.
27 Hence, the traditional approach to transmitting digitized signal
28 information over a crosslink is to multiplex the parallel output of

1 the analog to digital converter into an ordered serial data stream
2 synchronized by added synchronization frame word and adding
3 redundant error correction bits into the bit stream.

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5 At the receiver side of the communication channel, the
6 received incoming signal is processed in reverse order of the
7 processing of the data on the transmit side. Forward error
8 correction first corrects for transmission error while removing the
9 redundant error correction bits. Frame synchronization is
10 performed to determine the significance of the bits during which
11 the frame synchronization words are removed from the data stream
12 and the data is reclocked into a serial bit stream having a bit
13 time duration equal to the bit time during of the serial data
14 stream prior to frame synchronization in the transmitter. The
15 serial data stream is then converted back into the original n bit
16 parallel data words by sampling the serial data stream at the bit
17 time duration and clocking the serial bit stream into a serial to
18 parallel converter. The parallel data words for the serial to
19 parallel converter are then input into a digital to analog
20 converter for providing the original analog signal when an analog
21 signal output is desirable.

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23 It is desirable to eliminate the synchronization and forward
24 error correction so as to reduce that total amount of data bits
25 transmitted for improved channel communication efficiency. It also
26 desirable to eliminate reclocking of the serial data streams in
27 both transmitter and receiver reducing system complexity. One
28 problem with conventional communications crosslink is the

1 transmission of synchronization frame words and redundant error
2 correction data bits. Another problem with conventional
3 communications crosslinks is the power required for the additional
4 hardware needed to reclock the data streams at higher data rate
5 that further serves to decrease bandwidth efficiency.

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7 The communication channel may be laser crosslink. The laser
8 crosslink may not transmit analog signals directly with high power
9 efficiency. Analog signals must be converted to digital samples
10 and the bits transmitted must modulate the laser beam using digital
11 modulation, for example, phase shift keying or on off keying.
12 Small satellites, such as nanosatellites, are not able to generate
13 much power because of the small solar power collection area. The
14 use of laser crosslinks is desirable for transferring large amount
15 of data to another satellite for data processing. Low power
16 consumption components, and a reduction of the number of components
17 are required to meet power limited resources. The reduction of the
18 numbers of component is also desirable to increase reliability and
19 reduce fabrication complexity. One problem with conventional
20 crosslinks is the increased complexity for enabling frame
21 synchronization and forward error correction. Another problem with
22 laser crosslinks transmitting data streams is required additional
23 components for reclocking that complicate the crosslink design as
24 well as dissipating more power from the already power limited
25 resources.

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1 > 81 } Referring to Figures 1A and 1B, first and second order
2 modulators have been to modulate an analog input signal 10 into a
3 modulated output 12. The output 12 is a binary output. In the
4 first order sigma delta modulator of Figure 1 A. The input signal
5 in fed into a summer 14 providing an input error signal that is fed
6 into an integrated 16. The input error signal from the summer 14
7 is integrated by the integrator 16 to form an accumulated error
8 signal that becomes an input to a one bit quantifier 18. The
9 output of the one bit quantizer 18 is the binary output 12 and is
10 the sign of accumulated error signal. The output of the quantizer
11 18 is fed into the DAC 20 providing a converted error equal to a
12 gain amplifier 22. A gain amplifier 22 provides gain G of the
13 converted error signal from output of the DAC 20 to provide an
14 amplified error signal to the summer 14. The amplified error
15 signal output of the gain amplifier 22 is fed back into the summer
16 14 to be subtracted from the analog input signal 10 to provide
17 input error signal. Hence, the first order modulator comprises a
18 first order feedback loop. The first order feedback loop forces
19 the average of the converted error signal output of the DAC 20 to
20 be equal to the analog input signal 10 plus an error signal. The
21 output of the first order modulator 12 is a series of +1 or -1
22 pulses of varying duration. The second order modulator of Figure
23 1B, comprises a first order feedback loop and a second order
24 feedback loop. The second order feedback loop comprises a summer
25 14a, integrator 16a, a the one bit quantizer 18, a DAC 20a, and a
26 gain amplifier 22a, whereas the first order feedback loop comprises
27 a summer 14b, integrator 16b, the one bit quantizer 18, a DAC 20b,
28 and a gain amplifier 22b. The first order feedback loop serve to

1 generate a first order input error signal at summer 14b, while the
2 second order feedback loop serves to generate a second order input
3 error signal of first order input error signal. The presence of a
4 second order feedback loop reduces the magnitude of the overall
5 error at the binary output 12. The binary output 12 of the sigma
6 delta modulator is a series of pulses of +1 or -1 of varying
7 duration. Hence, the sigma delta modulators convert the analog
8 input 10 into the binary output 12. The sigma delta modulators
9 have been used as modulators for digital communications, and as
10 part of an analog to digital converter. These sigma delta
11 modulators have been used in analog to digital converters
12 comprising a sigma delta modulator and a digital filter. These
13 sigma delta modulators have also been to as opposing modulators and
14 demodulators in communication links for communicating an analog
15 signal by transmitting a binary communication signal through the
16 crosslink. In the sigma delta analog-to-digital converter, the
17 sigma delta modulator and digital interpolating filter are an
18 integrated package. While sigma delta modulators offer analog
19 signal modulation, these modulators have not been used for laser
20 crosslink communication where digital signal samples rather than
21 analog samples are desired. These and other disadvantages are
22 solved or reduced using the invention.

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Summary of the Invention

An object of the invention is to provide a laser crosslink communicating a binary signal using sigma delta modulation prior to transmission and digital filtering after reception.

Another object of the invention is to provide a laser crosslink for communicating a binary signal using sigma delta modulation prior to transmission and digital filtering after reception for generating a digital signal representative of the analog input signal.

The present invention is directed to a laser crosslink system between a transmitter and a receiver. An analog input to modulated by a sigma delta modulator providing a symbol data stream to a laser transmitter transmitting a binary communication signal. The binary communication signal is received by a laser receiver providing a symbol data stream to a digital filter that provides a digital output. Hence, the present invention is directed to communicating in binary form an analog signal using a sigma delta modulator and recovering a digital samples of the analog signal using a digital filter. The combination of the sigma delta modulator with the transmitter and the digital filter with the receiver enabling direct laser modulation of the binary signals communicated across the laser link.

1 The laser crosslink system requires fewer parts and less power
2 by integrating analog to digital conversion and transmission into
3 one system. The use of sigma delta modulator prior to transmission
4 reduces the roll-off requirements for anti-aliasing filters in the
5 front of the analog to digital converter of the satellite
6 transmitting the crosslink signal reducing manufacturing tolerances
7 and required performance. The sigma-delta modulator simplifies
8 laser crosslink design over traditional phase shift keying
9 modulation by direct modulation of the laser by the data stream.

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11 Sigma-delta modulator is a conventional sigma delta modulator
12 providing a binary +/- 1 output for providing on-off (0,1) signal
13 that is then fed directly into an on-off laser modulator providing
14 a binary communication signal. When the output of the laser
15 detector is a continuous voltage rather than a 0 or 1, then this
16 may be converted to an n-bit digital word between [-1,1] to
17 implement soft decision type of algorithms for the interpolation
18 function. The laser is used in a transmitter communicating through
19 the laser communication crosslink to another receiving satellite.
20 The receiving satellite has a simple digital filter detector which
21 determines when the received signal from the laser is on or off.
22 The communicated binary signal is converted to +1 or -1 and is
23 input to the digital filter. A conventional sigma delta analog to
24 digital converter comprising a sigma delta modulator and a digital
25 filter is essentially split with the modulator modulating the input
26 analog signal to be communicated in binary form and the digital
27 filter residing with the receiver for data detection using the
28 digital filter. The sigma-delta modulator and digital filter of

the conventional sigma delta converter are placed at physically separated locations on opposing ends of the communication crosslink. The laser crosslink integrates the conventional sigma delta analog to digital converter to simplify the design of the laser crosslink. By changing the clock speed, order of the sigma delta modulator on the transmitting satellite, and the size of the decimating digital filter on the receiving satellite, any number of bits of resolution, up to the bit capacity of the laser cross link, can be realized. The link may operate at high resolution and low capacity or low resolution and high capacity. The laser crosslink enable adaptation for different types of data resolution and link capacities without requiring different hardware.

The laser crosslink may exist through free space or through optical fibers. The high bandwidth available from the laser crosslink permits the direct transmission of the oversampled data stream output by the sigma-delta modulator. Since that output is oversampled and redundant already, this eliminates the normally required synchronization and error correction detection on the digital link. Since the digital sample is reconstructed using a digital filter filtering a continuous stream of data, it is less susceptible to errors in the transmission of data than in traditional framed data where the probability of error for bits is the same but the effects of errors is more severe with the most significant bits than with the least significant bits.

1 The laser crosslink system can be used as a satellite
2 communication system employing free space or fiber optic laser
3 crosslink where digitized information such as voice, received radio
4 signals is being transmitted to another location or satellite. One
5 application of small satellites is a constellation of satellites
6 containing signal receivers using nanosatellites. The digitized
7 samples of the received signals to other satellites for processing
8 over a laser crosslink. The laser crosslink can be used for other
9 uses including signal intelligence collection, digital
10 nonregenerative transponders, and fiber optics. The laser
11 crosslink offers the collection of low bandwidth signals with high
12 resolution at low power levels.

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14 The laser crosslink is well suited for use in small satellites
15 such as nanosatellites having very limited power resources. The
16 laser crosslink has reduced number of components reducing power
17 requirements. One application of small satellites is a signal
18 receiver that transmits digitized copies of the received signals to
19 other satellites for processing. This has uses in either signal
20 intelligence or for digital nonregenerative transponders. The
21 laser crosslink offers lower power consumption and fewer parts by
22 integrating a modulator and A/D converter with the transmitter and
23 receiver. The laser crosslink reduces filter requirements for
24 small satellite using direct modulation of a laser while reducing
25 manufacturing tolerances for smaller satellite. No specialized
26 modulator is required by the laser. No error correction is
27 required because redundancy is added by the oversampling of the
28 sigma delta converter. No synchronization is needed between the

1 two satellites because the output of the digital filter may be
2 sampled at any time to reconstruct signal samples. No framing is
3 needed in the data stream because the data stream is self
4 synchronizing. Also, there is no need to order bits from most to
5 least significant bits as in traditional digital data links because
6 only the duration of the bit time is required for proper data
7 detection. These and other advantages will become more apparent
8 from the following detailed description of the preferred
9 embodiment.

DRAFT EDITION
DRAFT EDITION

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2 **Brief Description of the Drawings**
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4 **Figure 1A is a schematic diagram of a first order sigma delta**
5 **modulator.**
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7 **Figure 1B is a schematic diagram of a second order sigma delta**
8 **modulator.**
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10 **Figure 2 is a block diagram of a laser communication system.**
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2 Detailed Description of the Preferred Embodiment

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4 An embodiment of the invention is described with reference to
5 the figures using reference designations as shown in the figures.
6 Referring to Figure 2, a laser communications crosslink system
7 receives an analog input 30 for communication as a communication
8 signal from a transmitter 32 through a communication medium to a
9 receiver 36 that provides a digital output 38 representing the
10 analog input signal 30. The digital output 38 is an n bit sample
11 of the analog input 30. The analog input 30 is modulated by the
12 sigma delta modulator 40 for providing +/-1 binary symbols that are
13 communicated as binary zero and one digital signals. The
14 communication medium maybe a free space satellite or terrestrial
15 laser crosslink or fiber optic cable. The input signal 30 is
16 modulated by a sigma delta modulator 40 providing a +/-1 modulated
17 input signal to the transmitter for transmission from the
18 transmitter 32 over a communication medium. The +/-1 modulated
19 output of sigma delta modulator is received by the transmitter 32.
20 The sigma delta modulator 40 produces pulse width modulated symbols
21 representative of the analog input signal 40. The transmitter 32
22 includes a symbol to binary converter 42 and a pulse laser
23 modulator for converting and pulse width modulating the modulated
24 signal from the sigma delta modulator 40. The symbol to binary
25 converter 42 converts analog voltages of the modulated signal from
26 the sigma delta modulator 40 into binary values of on or off
27 states. The symbol to binary converter 42 converts the +/-1
28 symbols to binary output of 0 or 1. The binary output of zero and

1 one values is the input to the pulse laser modulator 44 that turns
2 on or off a laser pulse depending upon whether a 0 or 1 is input
3 value. The pulse laser modulator 44 transmits binary values across
4 communication medium to the receiver 36. The laser pulses are
5 communicated over the communications medium 34 as the
6 communications signal.

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8 The receiver 36 includes a pulse width detector 46 and a
9 binary to symbol converter 48. The receiver 36 receives the
10 communication signal and detects the laser pulse widths and outputs
11 a digital symbol signal to a timing recover loop 52 and a digital
12 filter 50 that provides the digital output 38. The pulse width
13 detector 46 in the receiver detects the duration of laser pulses of
14 the communicated signal and provides binary values. The laser
15 pulses are received by the pulse width detector 36 in the receiver
16 34 and outputs a binary value one for the duration of the
17 communicated laser pulse. The binary to symbol converter 48
18 changes the binary output 0 or 1 from the detector 36 into +/-1
19 output symbols. The binary to symbol converter 48 converts binary
20 values from the pulse width detector 46 into the +/-1 binary
21 symbols. The +/-1 output symbols are communicated to the digital
22 filter 50 and the timing recovery loop 52 for generating a digital
23 output 38 having a value representing the analog signal at
24 corresponding symbol times. The digital filter 50 is a circuit
25 that filters the binary symbols signal and provides the digital
26 output signal clocked by the timing recover loop 52. The timing
27 recovery loop 52 is a circuit that recovers the sample times for
28 clocking the digital filter 50. The timing recovery loop 52

1 recovers from the symbol output a sample rate to provide a clock
2 signal to the digital filter 50 for clocking the digital output
3 signal 38. The digital output 38 is an n bit digital sample of the
4 analog input dependant upon the length and wordsize of the digital
5 filter.

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7 The sigma delta modulator 40 can be a first order sigma delta
8 modulator shown in Figure 1A or a second order sigma delta
9 modulator shown in Figure 1B. Additional integrators 16 and DACs
10 may be used to increase the order of the loop of the sigma delta
modulator. By increasing the order of the loop, the magnitude of
11 the error of the binary symbol output 12 of the sigma delta
12 modulator 40 is reduced. By increasing the order of the sigma
13 delta modulator 40, the sampling rate of the output symbol signal
14 12 is reduced and the error signal is reduced thereby reducing the
15 required transmission bandwidth over the communication channel.
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17 The oversampling of the sigma delta modulator 40 and a
18 corresponding amount of oversampling by the digital filtering 50
provide a form of forward error correction. By increasing the
19 amount of oversampling at the output of the sigma delta modulator
20 40, the overall errors in the digital output 38 maybe reduced.
21 Additional forward error correction can be realized by
22 oversampling.

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25 The transmitter 32 may further transmit a laser timing signal
26 that is in synchronism with the communicated pulse width modulated
27 laser signal. The pulse width detector 46 could be modified to
28 further detect the laser timing signal for generating a timing

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1 signal communicated to the digital filter 50 without the need for a
2 separate timing recovery loop. The size of the digital filter 50,
3 the order of the sigma delta modulator 40 and the sample rates
4 determine the complexity, effective numbers of quantization bits,
5 sampling errors, and bandwidth needed for the laser communication
6 crosslink system. The pulse laser modulator 44 may be an on off
7 shift keying or phase shift keying laser modulator. When the pulse
8 laser modulator 44 is a phase shift keying laser modulator,
9 transmitter 32 may be operated without the symbol to binary
10 converter 42. When the communication signal is a phase shift
11 keying signal, the pulse width detector 36 is a phase detector
12 providing the symbol signal directly to the digital filter 50
13 without the use of the binary to symbol converter.

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15 The receiver 36 may be modified to provide quantized sampled
16 levels for each received pulse. For received pulse quantization,
17 the pulse width detector 46 is replaced with an n bit pulse
18 amplitude quantizer and the binary to symbol converter 48 is
19 replaced with an n bit symbol converter 48 with multiple 2^n values
20 between +/-1 to enable inherent filtering by the digital filter 50
21 performing soft decision error correction.

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1 The laser communication crosslink system is preferably used
2 for communicating analog signals in digital form. The laser
3 communication crosslink system need not use parallel to serial
4 conversion, frame synchronization, data reclocking, nor forward
5 error correction. An analog signal may be communicated over the
6 communication medium in digital form for recovering a digital value
7 of the analog signal. Those skilled in the art can make
8 enhancements, improvements, and modifications to the invention, and
9 these enhancements, improvements, and modifications may nonetheless
10 fall within the spirit and scope of the following claims.

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